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THE RELATION OF CERTAIN NUTRITIVE ELEMENTS TO THE COMPOSITION OF THE OAT PLANT

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The study of the relation of various environmental factors to the composition of plants received its greatest stimulus when Emil Wolff published his studies on the analysis of plant ash to determine what constituents were to be found therein. Since that time an enormous quantity of literature has been contributed to the study, yet the work has never been satisfactorily concluded. Climate, availability of nutrients, water supply, and various other physico-chemical factors influence the composition of the straw greatly and of the grain or reproductive parts to a lesser extent.

W. Wolff (1864, 1865) and Hellriegel (1869) reported the first extensive study on the relation of mineral salts to plant composition. Not, however, until the voluminous work of E. Wolff (1871), did the study receive the attention of many of the best chemists in Germany. This pioneer study stimulated research until the investigations were taken up from several rather different yet related lines.

Von Heinrich (1882), Atterberg (1886, 1887), Dikow (1891), Helmkampf (1892), Stahl-Schröder (1904), Jakouchkine (1915), and Sawine (1916) sought by analysis of the whole plant or of its several parts to determine the availability of the mineral nutrients in the soil. On the other hand, Lawes and Gilbert (1856, 1884), Pagnoul (1875), and more recently LeClerc and Leavitt (1910), Raymond and Paturel (1910), Hartwell and Wessels (1913 *a, b*), Tretiakov (1913), Headden (1916 *a, b*), Davidson and LeClerc (1917), and Maschhaupt (1918) have studied the relation of environmental factors, chiefly fertility and climate, to the composition of the whole plant and of its respective parts. Griffiths (1884), Takeuchi (1908), Chirikov (1914), and Waynick (1918) have extended the investigations still farther by studying the effects of the addition of specific substances, in many cases in varying amounts, to the composition of the plant. Kossowitsch (1909) has taken still another phase of the problem, investigating the composition of different plants grown under the same nutritive conditions.

The work referred to up to this time has been primarily a study of the influence of these factors upon the composition of the ash constituents. Although it is not within the scope of this paper to discuss the relation of environmental factors to the organic composition of the plant, yet the study would not be complete without reference to the important literature on this phase of the investigation. Thacher (1913, 1917), Grisdale (1913), Tretiakov (1913), Headden (1916, *a*, *b*), and others have studied the relation of nutrition and climate to the protein composition of plants. Wiley (1901) and Wilfarth and Wimmer (1903) have shown that fertilizers and climate cause a marked variation in the sugar content of the sugar beet. Seissl and Gross (1902) state that the starch content of the potato is changed quite markedly by the addition of fertilizers. Parrozzani (1908) and Jakouchkine (1915) find considerable variation in the organically combined phosphorus of plants when different fertilizers are employed. Garner (1914) and others have shown that the oil content of plants is modified by the addition of certain fertilizer elements to the soil.

A review of this literature on the relation of plant environment to composition brings out two very striking facts: first, that the plant as a whole responds quite markedly to environment by changes in its composition, and second, that for no two cases are these responses the same. Most of the work on the relation of fertilizers to plant composition has been done in the field where sufficient quantities of most of the elements have been present to supply the minimum needs of the plant; therefore, the changes in composition, especially in that of the seed, have not been very marked. The conclusion has thus been drawn that the composition of the grain, the reproductive part, is very constant, while the response or change in plant constituents takes place in the leaves and stems of the plants.

It has been the purpose of the experiments herein recorded to study the effect of limiting certain essential nutrient elements upon the composition of the grain and straw of well matured plants when other environmental factors were controlled as far as possible.

The culture work from May to August, 1915, and May to August, 1916, was carried on under climatic conditions different from those that governed the latter part of the work, which differences may in some cases explain the differences between the data recorded for the two respective periods. A brief comparison of the meteorological data for the two periods has been included in the present paper.

From September, 1916, until the conclusion of the experiments the work has been carried on in the laboratory of plant physiology at the University of Wisconsin. It is a pleasure to acknowledge my indebtedness to Professor J. B. Overton for his advice and assistance in supplying the apparatus necessary during the course of the investigation. Acknowledgment is also gladly given Professor W. E. Tottingham for his advice and assistance in the analytical work necessary during the progress of the experiments.

METHODS

Cultural methods employed in growing the plants under varied nutritive conditions are given in detail in a previous paper (Dickson, 1918). In brief, the complete cultural series consisted of the "normal" solution—that is, Knop's solution—modified by the addition of 0.1 gram of sodium chloride per liter of solution, and diluted to one tenth the concentration usually listed (table 1); and of five further modified culture solutions in each of which one of the elements magnesium, calcium, potassium, phosphorus, and nitrogen was reduced to one tenth of the quantity present in the normal solution.

TABLE 1. *The Composition of the Modified Knop's Solution Used as the Normal Culture Solution*

Salts	Concentration of Salts Used in "Normal" Solution Grams per Liter of Solution	Percentage Composition
$Ca(NO_3)_2$	0.08	0.0533
KNO_3	0.02	0.0133
KH_2PO_4	0.02	0.0133
$MgSO_4$	0.02	0.0133
NaCl	0.01	0.0067
Total salt	0.15	0.1000

Although these deficient elements were reduced to such an extent that they seriously hindered the development of the plant, yet they did not in any case prevent the production of grain. In other words, the various nutritive elements were reduced to about the lowest concentration that would still support the production of grain by the plants growing therein. It was necessary, of course, to base the concentration of the element reduced in each solution on the constituents in greatest demand by the plant, namely, phosphorus and nitrogen, and then to prepare all of the solutions in which one of the essential nutritive elements is deficient with the same concentration of the deficient element. By reducing the amount of the various nutritive elements below that required for normal development, it was hoped to bring out more strikingly the relation of the elements to the composition of the plant.

The various cultural solutions were calculated and prepared upon the basis of equal osmotic concentration by varying to a slight degree the amount of sodium chloride added to the respective solutions. To state it differently, the required nutritive salts were added to the solution and their respective osmotic activity was calculated from the dissociation of each constituent salt, then sufficient sodium chloride was added—never enough to exert a toxic influence—to make the total osmotic concentration equal to that of the "normal" solution. It was not found practicable to take into account the effect of one constituent salt upon the dissociation of another in the culture solution, but the degree of dissociation of the various solutions was checked by the soluble salts present, by measurements of electrical conductivity, and by freezing-point determinations.

The quantity of sodium chloride used in balancing the modified nutritive solutions was in no case greater than that added to the normal solution, that is, 0.0067 percent of the total salts added (table 1). Therefore, the presence of this salt should have no appreciable difference in effect upon the

TABLE 2. *The Amounts of Salts in Solution, Electrical Conductivity, and Depression of the Freezing Point of the Normal and Modified Solutions*

Solution, Deficient Element Given	Total Soluble Salts in Grams per 100 Cc. of Solution			Conductivity × 10^{-5} Reciprocal Ohms			Depression of Freezing Point in Degrees Centigrade		
	1916 Sol.	1917 Sol.	Ave.	1916 Sol.	1917 Sol.	Ave.	1916 Sol.	1917 Sol.	Ave.
Normal	.110	.105	.107	1.363	1.507	1.435	.050	.051	.050
Mg 0.1		.105			1.556			.051	
Ca 0.1	.085	.070	.077	1.144	1.058	1.101	.050	.050	.050
K 0.1	.109	.082	.095	1.343	1.451	1.397	.050	.051	.050
P 0.1	.098	.090	.094	1.383	1.305	1.344	.050	.051	.050
N 0.1	.120	.109	.114	1.455	1.625	1.540	.050	.061	.055

development or composition of the plants produced in the respective solutions.

General Cultural Methods

Glazed earthenware jars were used for containers. The plants were grown in analyzed quartz sand to which was added the diluted nutritive solution. The solution in the culture jars was maintained as nearly as possible at 60 percent of the moisture-holding capacity of the sand.

Pedigreed Swedish select oats, *Avena sativa aristata*, were used in all the experiments. The plants were grown under an open glass house exposed to out-of-door conditions from May until August of each year. The cultural work from May to August, 1915, and from May to August, 1916, was carried on under climatic conditions different from those that governed the latter part of the work, which differences may in some cases explain the differences between the data recorded for the two respective periods. In a later part of this paper a comparison will be made of the meteorological conditions for the two periods.

The average grain and straw produced per pot for each year is given in table 3. It was not possible to produce large quantities of either grain or straw in the phosphorus- and nitrogen-deficient solutions. Therefore, the samples for analysis from these cultures were rather small, yet with special manipulation it was possible to secure results that checked very closely.

TABLE 3. *The Average Yield of Grain and Straw in Plants Grown in the Normal Solution and in Solutions with One Nutrient Element in Each Case Reduced to One Tenth Normal*

No. Det. per Year	Solution, Deficient Element Given	Weight of Grain in Grams			Weight of Straw in Grams		
		1915 Crop	1916 Crop	1917 Crop	1915 Crop	1916 Crop	1917 Crop
4	Normal	5.329±2	6.986±1	6.362±0	7.08±2	14.77±2	28.08±0
2	Mg 0.1			5.804±1			29.62±2
2	Ca 0.1	5.212±1	6.645±0	3.999±0	7.96±2	17.21±3	20.75±2
2	K 0.1	2.968±1	5.660±2	3.268±0	3.51±2	10.22±4	12.68±0
2	P 0.1	1.142±1	.390±1	.665±0	1.59±1	.84±1	2.11±2
2	N 0.1	1.767±1	.120±1	.679±0	2.23±1	.29±0	2.02±0

In most cases, the quantity of plant material produced was too small to permit the analysis of the grain and straw for all the essential nutrient elements limited in the cultural series; therefore, it was necessary to select certain of these plant constituents which would represent elements having a very definite chemical combination with many of the complex plant substances, and certain others whose action was more or less secondary in nature. Phosphorus and calcium were finally selected, and determinations were made for total phosphorus and calcium present in the oat grain and straw.

Analytical Methods

The well matured grain and straw were ground to a finely powdered mass after drying at 90° C. for 12 hours, and stored in tightly stoppered bottles for analysis. After the samples were dried to constant weight at 110° C. and thoroughly mixed, samples were weighed out for calcium and phosphorus determinations. Two-gram samples for grain and one-gram samples for straw were taken for the calcium determinations, and one-gram samples of both grain and straw were used for phosphorus determinations.

The official analytical methods as set forth in Bureau of Chemistry Bulletin 107, or standard methods which had been carefully checked with the "official methods," were employed in all cases.

All analyses were run in duplicate, and, in case they did not check within 0.5 percent, were repeated. In the cases of three samples, however, of which there was insufficient material, only one sample was analyzed. The results given in the tables are averages of these duplicate, or in some cases quadruplicate, determinations.

The samples for calcium determinations were ignited at low heat in a muffle until completely ashed, digested in hydrochloric acid, and finally filtered. Calcium was precipitated as calcium oxalate after removing the hydroxides of iron, aluminum, and phosphorus, and determined as CaO by titrating the oxalic acid with standard potassium permanganate.

The phosphorus samples were analyzed by the sodium-peroxide method as originally described by Osborne (1902) and modified by Dubois (1905). The sample was placed in a nickel crucible and moistened until it formed a thick paste, after which five grams of anhydrous sodium carbonate were added and the charge was mixed immediately. Five grams of sodium peroxide were then added in smaller portions at a time with thorough mixing after each addition. The mass was then heated until fusion was complete. Additional sodium peroxide was added to oxidize completely the organic matter. The mass was dissolved in concentrated hydrochloric acid, made up to 250-cc. and 100-cc. aliquot portions used for phosphorus determinations. These 100-cc. samples were evaporated to dryness over a water bath, taken up with hot water, strongly acidified with nitric acid, and phosphorus was determined by the "official gravimetric method."

The Relation between Nutrients and Calcium Content of Grain

The general conception has been that there is very little variation in the composition of the seeds or reproductive parts of plants. Lawes and Gilbert (1884) state that the composition of the grain is not greatly varied by normal variations in soil composition. Their ideas of the limits of variation of the grain can best be stated in their own words:

> The composition of the grain only varies in any marked degree according to manure, when there is a very abnormal deficiency of one or more constituents, having regard to the amount of growth which is induced by the liberal supply of others. The composition of the grain is very uniform, notwithstanding there may be a very great excess of supply, and a relatively very great excess taken up by the plant, in which latter case a large excess remains in the straw.

As previously stated, the earlier studies on composition have usually been made on plants which were grown under field conditions in soil of low or high fertility, or, in other words, where the supply of the available nutritive elements was not under strict limitations. It is evident from the data presented in table 4 that the calcium content of the grain varies greatly when the supply of available nutritive elements is limited to a definite small amount.

TABLE 4. *The Average Calcium Content of Grain from Plants Grown in the Normal Solution and in Solutions with one Nutrient Element in Each Case Reduced to One Tenth Normal*

Solution, Deficient Element Given	Percent CaO in Grain			
	1915 Crop	1916 Crop	1917 Crop	Average
Normal	0.317	0.405	1.360	0.694
Ca 0.1	0.042	0.061	0.180	0.094
Mg 0.1			1.422	0.729
K 0.1	0.216	0.227	1.760	0.734
P 0.1	0.275	0.284	0.540	0.367
N 0.1	0.305	0.548	0.500	0.451

The plants grown in culture solutions deficient in calcium—one tenth the amount in the normal culture solution—produced grain of very low calcium content, an average of ten percent lower than the calcium content of the grain produced in the normal solutions.

Physiologists and biochemists consider the rôle of calcium as secondary in the formation of seed. Therefore, possibly it may be replaced to a greater or less extent by certain other bases, notably potassium and magnesium. Some proof supporting this hypothesis is given in the fact that the average calcium content of the grain produced in magnesium-deficient and potassium-deficient solutions is relatively high. The low calcium content of the grain produced in potassium-deficient solutions during the first two years, however, would indicate that this is not true under all environmental conditions. The calcium content of the grain produced in the phosphorus- and nitrogen-deficient solutions during the first two seasons is quite high.

These samples were rather small, however, and therefore the data are not as accurate as desired. The calcium content of the grain from the phosphorus- and nitrogen-deficient solutions for the last year (1917 column, table 4) in which the total number of plants was greatly increased, making more material available for analysis, is considerably lower than in any of the other samples. The data for these last two series, namely, phosphorus- and nitrogen-deficient cultures, are too varied to draw any conclusions. In the case of the other samples, however, it is quite evident that a marked variation in the nutritive solution produces a very considerable change in the calcium content of the grain.

It is held by some that calcium and magnesium function in the translocation of carbohydrates and proteins and in the storage of these compounds during seed formation, rather than being directly connected with the synthesis of the carbohydrates and proteins that are later transferred to the seed. Calcium probably functions in this capacity much less than does magnesium, as analyses show a scarcity of calcium and an abundance of magnesium in most seeds. Magnesium probably functions, therefore, as the chief carrier of phosphoric and other acids entering into the chemical composition of the seed, while calcium acts more as a neutralizer of acids resulting from synthesis. Bernardini (1914) describes quite fully the functions of magnesium and its probable relation to translocation processes. This indirect function of calcium was first pointed out by Holzner (1867) and Schimper (1890), and more recently has been supported by Chirikov (1914), Robert (1917) and others.

Truog (1916) states that plants with a high protein content generally have a high calcium content and that when manganese phosphate is used instead of calcium phosphate as a source of phosphorus the plants grown in such a solution have an extraordinarily high manganese content. Robert (1911, 1912) attempts to show that calcium is deposited directly within the fungus as a calcium salt of certain organic acids. She shows that an increase of calcium in the culture solutions results in a very marked rise in the calcium content of the fungus.

In general, a deficiency of calcium in the nutritive solution results in the production of grain with a very low calcium content, while on the other hand a deficiency of magnesium or of potassium in the culture solution causes a slight accumulation of calcium in the grain of the plants grown therein. The effect of a deficiency of either phosphorus or nitrogen generally results in the production of grain with a low calcium content. The calcium content of the grain of oat plants grown under varied nutrient conditions is considerably altered by the composition of the nutrient solutions in which the plants grow.

THE RELATION BETWEEN NUTRIENTS AND CALCIUM CONTENT OF STRAW

The calcium content of the straw of the oat plant varies in a way in general similar to, although more marked than, that characteristic of the grain. Lawes and Gilbert (1884) have shown that the composition of the straw (leaves and stems) of various plants may be modified very markedly by the addition of nutritive elements as well as by the subtraction of these elements. The results have been so consistent in field work of this nature as to lead certain investigators to suggest that the composition of the grain, the reproductive part of the plant, is very stable, while the variation, if any occurs, is in the straw and roots. The average percentages of calcium in the straw produced in the different culture solutions are given in table 5.

TABLE 5. *The Average Calcium Content of Straw from Plants Grown in the Normal Solution and in Solutions with One Nutritive Element in Each Case Reduced to One Tenth Normal*

Solution, Deficient Element Given	Percent CaO in Straw			
	1915 Crop	1916 Crop	1917 Crop	Average
Normal	2.315	2.176	4.850	3.114
Ca 0.1	0.520	0.220	0.485	0.408
Mg 0.1			4.030	2.589
K 0.1	2.362	1.666	4.260	2.763
P 0.1	3.175	1.072	0.935	1.727
N 0.1	1.288	1.335	1.935	1.519

The average calcium content of the straw from the calcium-deficient solutions—containing one tenth of the calcium present in the normal solution—is only 13 percent of that of the straw produced in the normal cultures. The calcium content of the straw from the potassium-deficient solutions, although high comparatively speaking, is not as high as in the grain from the same set of cultures. The calcium content of the straw of the plants from the phosphorus-deficient cultures is considerably lower than that of the plants from the nitrogen-deficient solutions, and in both it is lower than the calcium content of the check plants.

In general, a deficiency of calcium in the culture solution causes a very marked lowering of the calcium content of both grain and straw of plants grown therein. A deficiency of potassium or of magnesium does not greatly affect the intake and storage of calcium either in the grain or in the straw. A deficiency of either phosphorus or nitrogen causes a lowering of the calcium content of both grain and straw; especially is this true for plants in the phosphorus-deficient solutions. The average composition of the plants for the three years is given in table 8, and in graphic form in figure 1.

THE RELATION BETWEEN NUTRIENTS AND PHOSPHORUS CONTENT OF GRAIN

Phosphorus, unlike calcium, enters into chemical combination with a great many of the plant compounds, especially with those of the seed.

Phospholipins, nuclein and nucleic acid, phytin, and possibly starch contain phosphorus in chemical combination. In addition to these organic compounds, some inorganically combined phosphates are stored in the seed, and often large quantities are deposited in the straw of the cereals. Probably, lecithin and phytin are the only organic compounds containing phosphorus which are accumulated as reserves in the seed, and which are, therefore, subject to variation due to the supply of phosphorus. Parrozzani (1908) found that the percentages of both lecithin and phytin phosphorus were increased by the addition of mineral phosphate fertilizers to the soil. The nuclein phosphorus, on the other hand, was quite constant, showing no change even with the most varied phosphorus fertilization. Jakouchkine (1915) stated that the amount of phytin in the grain is apparently dependent on the condition of the soil. Generally only small amounts of inorganically combined phosphorus are stored in the grain; therefore, if the total phosphorus of the grain varies with varying amounts in the soil, it is probably due to the varying amounts of the organic reserve materials containing phosphorus. An organic analysis is necessary to disclose these relations and is planned in further pursuit of this problem.

The composition of the grain from plants grown in culture solutions having a deficiency of certain nutrient elements, especially of phosphorus, is modified very markedly. The average percentages of total phosphorus in the grain from plants grown in the different culture solutions are given in table 6.

TABLE 6. *The Average Phosphorus Content of Grain from Plants Grown in the Normal Solution, and in Solutions with One Nutrient Element in Each Case Reduced to One Tenth the Normal Amount*

Solution Deficient Element Given	Percent P_2O_5 in Grain			
	1915 Crop	1916 Crop	1917 Crop	Average
Normal	0.673	1.047	1.900	1.206
Ca 0.1	0.946	1.017	2.130	1.364
Mg 0.1			1.720	1.092
K 0.1	0.625	0.963	1.665	1.084
P 0.1	0.472	0.732	0.453	0.552
N 0.1		1.121	1.552	1.336

The phosphorus composition of the check plants which were grown in a complete nutrient solution varies over the three years' experiments. These variations for the different years will be discussed later under another heading. The phosphorus content of the grain from the plants grown in the calcium-deficient solutions is the highest of any of the series, the average content for the three years being 0.158 percent higher than the composition of the grain from the checks. The explanation for this extra high phosphorus content may be sought from two different sources: first, the calcium-magnesium ratio of the Knop's solution may not be the best for maximum translocation of phosphates, if, as is thought by a number of biochemists, magnesium is the chief carrier of phosphoric acid; and second, the calcium in the normal Knop's solution may be present in sufficient quantity to react with the phosphates to form the less soluble tricalcium phosphate, thus making the phosphorus present less available for the plant. The nitrogen-deficient culture solutions, likewise, produced plants with grain having a very high total phosphorus content. In all probability the factors concerned here are very complicated, as the deficiency of proteins would be apt to upset normal metabolism and therefore to produce very abnormal results within the plant. It is quite possible that much of the phosphorus in this latter case may be stored as the mineral phosphate in combination with the large amounts of bases present. The nutrition of the plant in this case is undoubtedly very much disturbed and very abnormal. A deficiency of potassium in the culture solution, on the contrary, results in the production of grain with a low phosphorus content, the average phosphorus content for the three years being 0.122 percent lower than in the check. The greatest reduction in phosphorus content, however, is in the grain from phosphorus-deficient solutions. The phosphorus content of this grain is reduced to 46 percent of the phosphorus present in the grain from the checks. In all probability the reduction took place in the amount of phytin and lecithin stored in the grain. In general, then, there is a very marked variation in the phosphorus content of grain produced under different nutritive conditions. A deficiency of phosphorus or of calcium causes the greatest variation, the lack of the former element producing a very marked decrease, that of the latter a moderate increase in phosphorus content.

The Relation between Nutrients and Phosphorus Content of Straw

The composition of the straw generally shows more marked variations than that of any other part of the plant, unless it be the roots, for the unassimilated excess salts are stored here in the case of the addition of large amounts of specific elements, and on the other hand the straw releases

Table 7. *The Average Phosphorus Content of Straw from Plants Grown in the Normal Solution and in Solutions with One Nutrient Element in Each Case Reduced to One Tenth the Normal Amount*

Solution, Deficient Element Given	Percent P_2O_5 in Straw			
	1915 Crop	1916 Crop	1917 Crop	Average
Normal	0.309	0.734	0.832	0.628
Ca 0.1	0.415	0.354	1.230	0.667
Mg 0.1			0.892	0.673
K 0.1	0.265	0.334	0.682	0.427
P 0.1	0.092	0.060	0.051	0.068
N 0.1	0.834	1.750	1.805	1.463

the deficient substances quite rapidly in order that they may be stored in the reproductive parts of the plant. A wider variation in the composition of the straw is, therefore, to be expected. The results, as set forth in table 7, show this to be true. The variations in composition due to varied nutritive conditions are similar to, though more marked than, those of the grain. The extremely high phosphorus content of the straw from the nitrogen-deficient solutions confirms the idea that the phosphorus metabolism is blocked by the deficiency of proteins, and that, therefore, phosphorus in the inorganic form piles up to some extent in the grain, but more markedly in the straw. The phosphorus content of the straw produced in the phosphorus-deficient culture solutions is very low, the average for the three years being approximately 10 percent of the amount present in the straw from the normal solutions. The variations in the composition, although more pronounced in the straw, yet in general are identical with those in the grain.

TABLE 8. *The Average Composition of Plants Grown in the Normal Solution and in Solutions with One Nutrient Element in Each Case Reduced to One Tenth the Normal Amount*

Solution, Deficient Element Given	Percent CaO		Percent P_2O_5	
	Grain	Straw	Grain	Straw
Normal	0.697	3.114	1.206	0.628
Ca 0.1	0.097	0.408	1.364	0.667
Mg 0.1	0.729	2.589	1.092	0.673
K 0.1	0.734	2.763	1.084	0.427
P 0.1	0.366	1.727	0.552	0.068
N 0.1	0.451	1.519	1.336	1.463

In summation, comparing the composition of the plants from the modified solutions with the composition of those from the normal, a deficiency of phosphorus in the culture solution causes a very marked lowering of the phosphorus content of both grain and straw of the plants grown in these solutions. A deficiency of either calcium or nitrogen causes an increased intake of phosphorus especially in the straw. A deficiency of potassium causes a slight reduction in the amount of phosphorus accumulated in the grain and a more marked reduction of phosphorus in the straw. Magnesium deficiency in the culture solutions causes a slight decrease of phosphorus in the grain of plants grown in these solutions, and a small increase in the phosphorus content of the straw. The average composition of the plants for the three years is given in table 8, and in graphic form in figure 1.

THE RELATION OF CLIMATE TO THE COMPOSITION OF THE OAT PLANT

The experiments of Lawes and Gilbert (1884), Cserhati (1908), Grisdale (1913), and Tretiakov (1913) have shown very strikingly that the factors of climate and geographical location cause a wide variation in the composition of plants. Lawes and Gilbert (1884) explain these variations by deviations from the normal maturation of the plant. They sum up their results very well in the following statements:

> The character of the crop left to ripen depends very much more upon season than upon manuring. There is scarcely any difference in the composition of the truly and normally ripened seed. The wide range in the composition of the ash of the grain represents a corresponding deviation from the normal development.

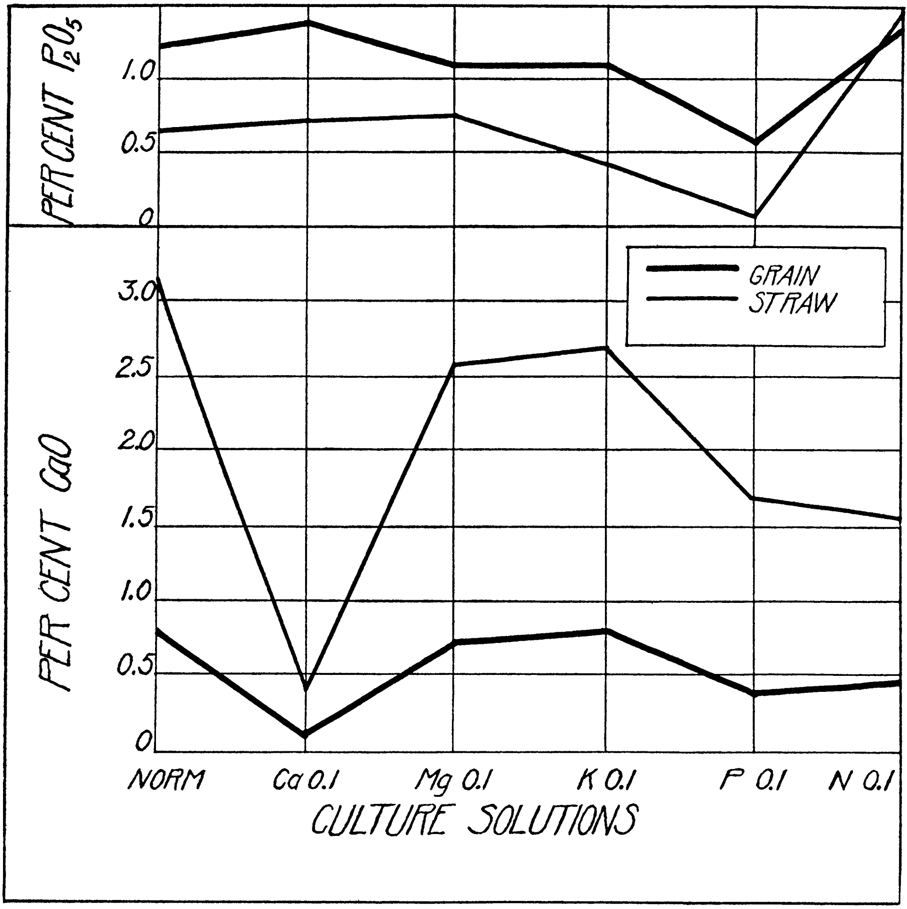

FIG. 1. Curves showing the average composition of grain and straw of plants grown in the normal solution and in solutions with one nutrient element in each case reduced to one tenth the normal amount.

Likewise LeClerc and Leavitt (1910) attribute the variations in composition of wheat primarily to different climatic conditions and to the effect of these climatic factors upon plant growth and maturation. It is undoubtedly true that environmental factors which alter normal development and maturation have an extremely great influence upon the composition of crops grown in the field or in artificial culture. In artificial cultures, however, it is possible to alter the growth and maturation of the plant much more by the deficient nutrients than by climatic factors; therefore, it is reasonable to suppose that the deficient nutrient may have as much influence upon the composition as the climatic variations. This is not, however, minimizing the effect of climate, and such environmental factors must be taken into consideration in all studies of this sort whether they be field or culture experiments.

The analytical data previously discussed in connection with nutrition, when studied from another angle, that of the relation of climate and geographic location to composition, show how closely the influences of these various factors are interrelated. The combination of temperature, humidity, and other climatic conditions greatly influenced the composition of the plants except when the reduction of certain essential nutritive elements became the predominant factor in controlling plant development. Under these conditions, variations due to other environing factors were outweighed by the deficient nutritive element.

TABLE 9. *The Average Composition of Plants grown under Different Climatic Conditions*

	Composition of Plants in Percentage Based on Dry Weight		
	Pullman, Washington		Madison, Wisconsin
	1915	1916	1917
Average composition from all cultures			
CaO content of grain	0.231	0.305	0.960
P_2O_5 content of grain	0.679	0.976	1.570
CaO content of straw	1.932	1.294	2.416
P_2O_5 content of straw	0.383	0.646	0.915
Composition of check plants			
CaO content of grain	0.317	0.405	1.360
P_2O_5 content of grain	2.315	2.176	4.850
CaO content of straw	0.673	1.047	1.900
P_2O_5 content of straw	0.309	0.734	0.832
Composition of plants grown in Ca-deficient solution			
CaO content of grain	0.042	0.061	0.180
CaO content of straw	0.520	0.220	0.485
Composition of plants grown in P-deficient solution			
P_2O_5 content of grain	0.472	0.732	0.552
P_2O_5 content of straw	0.092	0.060	0.051

The analysis of plants grown in 1915 and in 1916 at Pullman, Washington, show in general a smaller accumulation of both calcium and phosphorus than in the last year, 1917, in which the plants were grown at Madison, Wisconsin. The phosphorus content of both grain and straw of plants grown in the complete nutrient solution and in the solutions with one nutritive element in each case reduced to one tenth that in the control solution, with the exception of the phosphorus-deficient solution, show consistent variations for the three years. With few exceptions, the phosphorus content is highest in the 1917 samples and lowest in the 1915 samples.

The average phosphorus content of all the grain analyzed each year, as given in table 9, is: 0.679 percent in 1915, 0.976 percent in 1916, and 1.570 percent in 1917. The increases in phosphorus content of the straw are equally great. This stands out in extreme contrast with the phosphorus content of the grain and straw of the plants grown in the phosphorus-deficient solutions, which show no influence of climate on composition. The calcium content of the grain produced in all the cultures, including the calcium-deficient solutions, is highest in 1917 and lowest in 1915. The calcium content of the straw, on the other hand, is not greatly influenced by seasonal differences. Certain other differences are brought out in comparing the data presented in tables 4 and 7 and summarized in table 9, but before they can be discussed intelligently a more complete analytical study is necessary together with more detailed meteorological records.

TABLE 10. *The Mean Daily and the Average Monthly Air Temperatures at Pullman, Washington, and Madison, Wisconsin, for the Duration of the Cultural Experiments*

Days	Mean Daily Air Temperature by Months											
	May			June			July			August		
	Pullman		Madison	Pullman		Madison	Pullman		Madison	Pullman		Madison
	1915	1916	1917	1915	1916	1917	1915	1916	1917	1915	1916	1917
1......	38	52	42	56	51	53	70	57	69	74	64	72
2......	45	54	42	44	52	48	72	53	61	80	63	68
3......	51	55	46	57	52	60	74	51	59	70	63	68
4......	55	—	38	63	57	61	72	55	64	69	61	72
5......	58	—	40	65	46	54	62	60	68	76	62	73
6......	58	51	44	62	52	59	66	62	66	70	67	68
7......	60	38	48	64	56	54	63	69	70	71	67	68
8......	60	42	48	55	60	61	60	73	75	70	60	62
9......	55	37	46	53	52	64	62	67	69	75	62	62
10......	48	37	50	49	49	68	60	61	66	77	66	64
11......	53	40	48	48	51	67	66	68	65	76	67	70
12......	51	44	50	54	57	71	65	74	65	71	70	64
13......	52	43	50	59	61	61	57	63	67	72	69	65
14......	51	46	57	61	65	50	53	64	68	76	71	68
15......	49	51	68	62	69	52	58	71	70	77	64	72
16......	58	56	68	61	73	56	63	69	66			
17......	55	58	70	63	76	66	56	52	68			
18......	49	51	69	51	60	71	63	54	70			
19......	47	47	68	53	47	64	69	62	74			
20......	50	45	50	60	45	64	73	66	76			
21......	54	42	42	63	42	67	82	66	78			
22......	50	52	40	70	54	59	79	65	74			
23......	52	53	44	72	61	59	72	64	76			
24......	54	54	52	65	60	61	74	66	76			
25......	52	59	56	59	66	68	72	60	80			
26......	53	53	51	54	58	73	69	55	81			
27......	61	55	52	58	59	66	66	61	75			
28......	57	50	54	62	49	60	66	61	78			
29......	51	48	60	59	50	68	56	64	85			
30......	55	55	60	63	55	70	65	71	86			
31......	62	50	62	—	—	—	68	71	84			
Average...	53	49	52	59	56	62	66	63	72	74	65	69

TABLE 11. *The Average Monthly Air Temperature at Pullman, Washington, and Madison, Wisconsin, for the Duration of the Cultural Experiments*

Month	Temperature °F. at Pullman, Washington		Temperature °F. at Madison, Wisconsin
	1915	1916	1917
May	53	49	52
June	59	56	62
July	66	63	72
August*	74	65	68

* The August temperatures are from the first to the fifteenth inclusive.

TABLE 12. *The Average Monthly Precipitation at Pullman, Washington, and Madison, Wisconsin, for the Duration of the Cultural Experiments*

Month	Rainfall in Inches at Pullman, Washington		Rainfall in Inches at Madison, Wisconsin
	1915	1916	1917
May	2.77	1.56	3.33
June	0.53	2.34	6.47
July	0.77	0.45	3.10
August	0.00	1.24	2.72

The important meteorological data for the periods during the growth and maturation of the plants are given in tables 10 and 11 and in graphic form in figure 2. The climatic differences for the three years, the first two at Pullman, Washington, and the last at Madison, Wisconsin, are summarized as follows: The 1915 growing season was very dry and cool, with high temperatures during maturation; the 1916 season was moderately dry and cool; the 1917 period was very wet and hot. The light intensity during the last year was considerably lower than during the first two seasons.

No attempt is made to correlate the variations in composition with any individual factor, for it is impossible to do more than speculate until controlled experiments have been run to determine the relation of such factors as light intensity, air and soil temperature, and humidity on the development and composition of plants.

SUMMARY

1. The calcium content of both grain and straw is reduced to about 10 percent of that of the plants from the controls by reducing the calcium in the culture solution to one tenth the quantity present in the complete nutrient solution. It is greatly reduced in both grain and straw by a similar deficiency in phosphorus or in nitrogen.

2. The total phosphorus content of the grain is reduced to 46 percent, and of the straw to 10 percent, of that in the plants from the controls by reducing the phosphate in the culture solution to one tenth of the quantity

present in the complete nutrient solution. It is slightly reduced in both grain and straw by a similar deficiency in potassium, and is increased by a similar reduction of calcium or nitrogen.

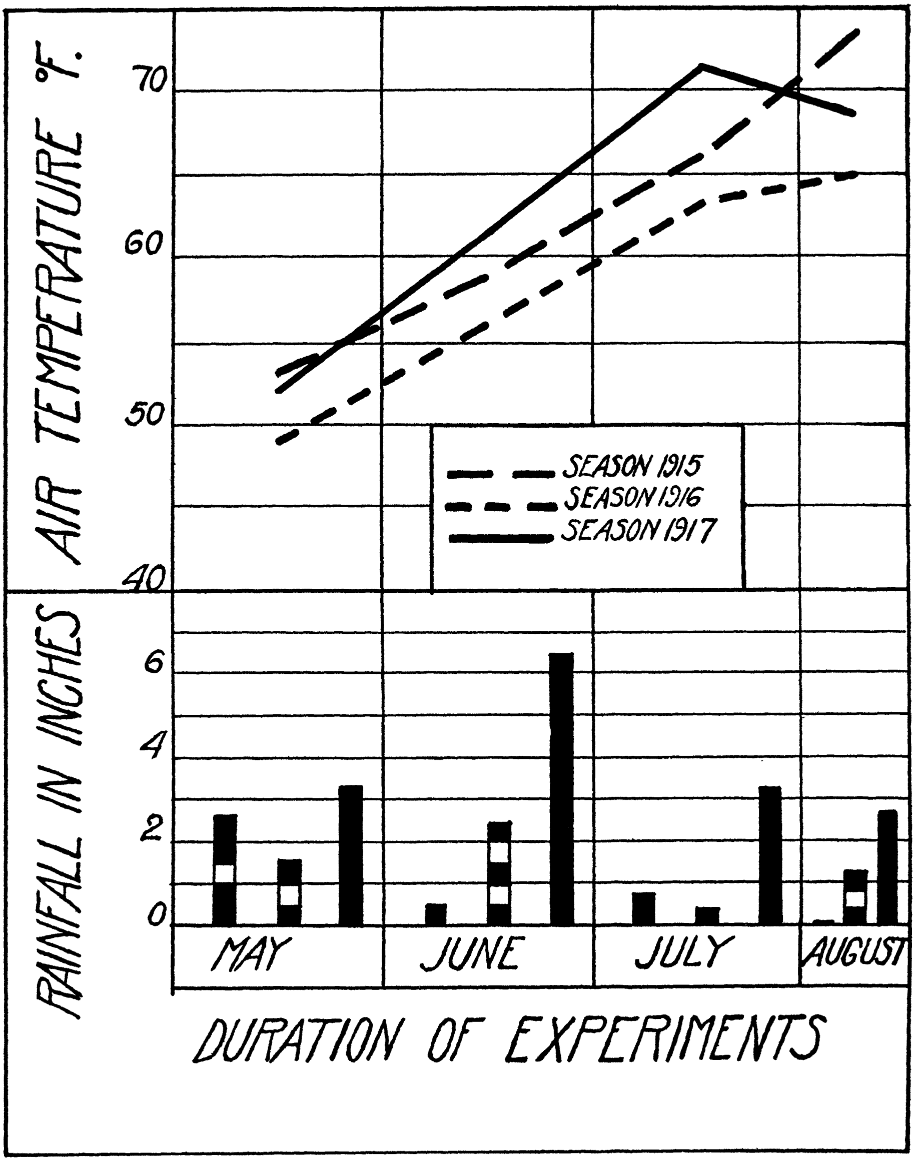

FIG. 2. Graphic representation of the average monthly temperatures and average monthly precipitation at Pullman, Washington, and Madison, Wisconsin, for the duration of the cultural experiments.

3. Although the variations in composition are more pronounced in the straw, yet in general they are similar in both grain and straw.

4. The phosphorus content of both grain and straw is modified by seasonal differences, except for the plants grown in the phosphorus-deficient solutions. The calcium content of the grain is modified by seasonal differences even in the calcium-deficient solutions. The calcium content of the straw, however, shows no consistent response to climate.

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